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No. 812.

THE DISTORTION OF RIVETED PIPE BY BACK-FILLING.

BY D. D. CLARKE, M. Am. Soc. C. E.
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WITH DISCUSSION.

During the years 1893 and 1894 there was constructed by the Water Committee of the City of Portland, Ore., and under the immediate supervision of the author as principal assistant engineer, a conduit 30 miles in length, for the purpose of bringing, for the supply of the city, the waters of Bull Run River, a beautiful mountain stream having its source a few miles distant from the base of Mt. Hood.

For 24 miles of the distance the conduit consists of a riveted steel pipe, the several sections of which are 33, 35 and 42 ins. in diameter. For the 42-in. pipe the plate varied in thickness from No. 6, B. W. G., to $\frac{3}{8}$ in., or 0.22 to 0.375 in. The 33-in. and 35-in. sections were made of No. 6 plate, B. W. G.*

The specifications for the manufacture of the plate called for steel having a tensile strength of 55 000 to 65 000 lbs. per square inch, with an elastic limit of 30 000 lbs. per square inch, and capable of being

* See *Transactions*, Vol. xxxvi, p. 197.

bent 180° when cold and hammered down flat without sign of fracture. The record of tests made during the process of manufacture shows that the plate was fully up to the standard for tensile strength and elasticity. The pipe trench was excavated chiefly in a clayey soil, but in a few places cement-gravel and boulders were encountered. The average depth of the trench was from 7 to 8 ft., but for short distances the depth was sometimes as great as 11 ft.

In January, 1894, while some of the employees of the contractors were at work inside a section of the 35-in. pipe, they discovered that the top of the pipe had been flattened, apparently by the weight of the earth covering. This having been brought to the attention of the author, he at once caused an examination to be made, with a view of determining the extent of the flattening of the pipe and its probable cause.

At that time there had been laid 8 miles of 35-in. pipe and about 1 mile of 42-in. pipe of No. 6 plate.

Measurements of the inside diameter of the pipe then laid were made at various points, particularly where the trench had been the deepest, and it was found that the crown of the pipe had been flattened quite generally, the amount of such flattening varying from ½ in. to a maximum of 4 ins.

As the greatest depression was not found uniformly at the points where the pipe was buried the deepest, the conclusion seemed unavoidable that the earth had not been properly tamped around the pipe when the back-filling of the trench was being done. From this examination it also appeared probable that the top of the pipe had been flattened to a greater or less degree throughout its entire length, and the question therefore arose at once as to the effect, if any, which this distortion might have upon the caulking of the seams.

Having reported to the chief engineer, Isaac W. Smith, M. Am. Soc. C. E., since deceased, the action that had so far been taken and the discoveries resulting therefrom, he immediately directed the author to make a series of experiments with the view of ascertaining if the pipe had been injured in any way by the changes in its shape which had been noticed. This step was taken in order to be prepared for any possible claim which might arise in the final settlement with the contractors.

In conducting these tests the design was to reproduce as nearly as possible the conditions under which the pipe had so far been laid, as to depth of trench, weight of covering, etc. With this end in view a plank box was constructed 20 ft. long, 8 ft. high, and having a top and bottom width to correspond to the average dimensions of the trench, 4½ ft. at the bottom and 5½ ft. at the top (Fig. 1). In this box was placed a section of the pipe 29 ft. 3 ins. long, the usual length of the sections as they came from the shop. Each section consisted of alternate large and small plates, six in all. The box was then filled with coarse sand, weighing about 80 lbs. per cubic foot. The sand was carefully packed around and over the pipe for a distance of 20 ft. along its central portion, the pipe projecting about 5 ft. at each end of the box.

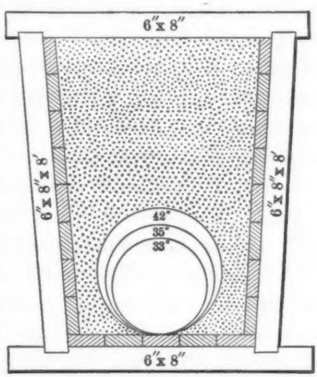

Fig. 1.

Test No. 1.—This was made with a section of the 33-in. pipe of No. 6 plate. The sand was carefully tamped to a height of 5⅝ ft. above the top of the pipe. The approximate weight was 460 lbs. per square foot. The vertical and horizontal diameters on the inside of the small courses were carefully measured at the center and at a point 10 ft. on each side of the center, or 5 ft. from each end of the pipe. These measurements were taken before the pipe was covered, and again after it had been standing covered for forty hours, when it was found that the top of the pipe had been depressed ⅜ in. After removing the sand from the box, the pipe was again measured and found to have regained its original form.

Test No. 2.—The pipe used in Test 1 was covered with sand loosely piled to a depth of 3 ft. above the top of the pipe. This load caused a depression of $\frac{3}{16}$ in. The pipe was then covered to a depth of 5⅝ ft., which depressed the top between ¼ and ⅜ in. Upon removing the load, the pipe came back to its original dimensions.

Test No. 3.—The 33-in. pipe used in Tests 1 and 2 was next braced on the outside with timbers wedged against the sides of the box. These timbers were placed at the center and at points about midway

between the center and each end of the pipe, and were wedged in so as to compress the sides of the pipe slightly. Upon filling the box with loose sand a depression of the top of the pipe was noticed, varying from $\frac{5}{16}$ to $\frac{7}{16}$ in., showing that a thorough tamping of sand around the pipe made a better support than the timber braces. Upon uncovering the pipe and removing the braces, the pipe regained its former vertical diameter within $\frac{1}{16}$ in.

This concluded the tests of the 33-in. pipe. The loads applied were equal to the average weight of the pipe covering in the trench, and, upon removing them, the pipe practically regained its original form in each instance.

Test No. 4.—This was made with a section of 42-in. pipe, No. 4 plate. This pipe was placed in the box and covered with carefully tamped sand to a depth of $5\frac{1}{4}$ ft. After standing fifteen hours the measurements taken showed a vertical compression varying from $\frac{1}{4}$ to $\frac{7}{16}$ in. When unloaded the pipe regained its original form.

Test No. 5.—For this test a section of 42-in. pipe of No. 6 plate was used. The sand was tamped solidly to a height of $5\frac{1}{4}$ ft. above the crown of the pipe. The estimated weight was 420 lbs. per square foot. This caused a depression of the top varying from $\frac{7}{16}$ to $\frac{9}{16}$ in. Upon removing the load, the pipe regained its former diameter.

Test No. 6.—The same pipe used in Test 5 was then supported on the sides by timbers placed at $7\frac{1}{2}$ ft. centers and wedged against the sides of the box. The pipe was next covered with sand, thoroughly tamped as in Test 5, and in addition some iron castings were distributed along the center of the pipe on top of the sand, making a total load of 520 lbs. per square foot, equal to that of a fill of $6\frac{1}{2}$ ft. above the top of the pipe. This load depressed the top of the pipe $\frac{7}{16}$ in. When the load and braces were removed, the pipe regained its former vertical dimensions, with a variation of $\frac{1}{8}$ in. at one point only.

Test No. 7.—In order to show the effect of more severe treatment, the section of pipe used in Test 6 was again placed in position, and a timber platform placed on top of it and loaded with iron castings, the sides of the pipe not being supported in any manner. A load weighing 17 600 lbs. was then applied, which caused a maximum compression of $1\frac{5}{8}$ ins.; upon removing the load, the pipe regained its former vertical diameter within $\frac{1}{4}$ in.

The pipe was then removed from the box and subjected to an in-

ternal hydrostatic pressure of 150 lbs. per square inch, but no leaks appeared.

Test No. 8.—The pipe used in Test 7 was again placed in position without support for the sides, and the top was loaded with a box filled with sand weighing 36 000 lbs. After supporting this load for 40 hours, measurements of the vertical diameter showed a compression ranging from $3\frac{1}{2}$ to $4\frac{3}{16}$ ins. On removing the load, the pipe regained its former vertical diameter within $\frac{3}{8}$ in.

Test No. 9.—The pipe used in Test 8 was covered with sand, thoroughly tamped, to a depth of $5\frac{1}{4}$ ft. on the top of the pipe, and the sand saturated with water. This caused a depression of the top varying from $\frac{3}{4}$ to 1 in., the pipe regaining its former dimensions upon removing the load. The pipe was again subjected to 150 lbs. per square inch hydrostatic pressure, but no leaks appeared.

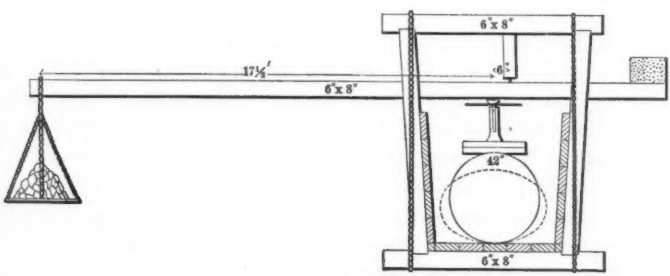

FIG. 2.

Test No. 10.—As a final test the pipe section used in Tests 5 to 9, inclusive, was again placed in position, and by means of three jack screws, placed one at the center and one 5 ft. from each end, the pipe was compressed $8\frac{3}{16}$, $8\frac{11}{16}$ and $8\frac{3}{4}$ ins. at the several points. By an arrangement of levers (Fig. 2), the pressure required to produce this effect was found to be 13 390, 14 190 and 15 170 lbs., or a total of 42 750 lbs. A final test to 150 lbs. per square inch hydrostatic pressure failed to discover any leak in the pipe. Measurements taken after the pipe was removed from the hydrostatic press showed a permanent set of $1\frac{11}{16}$ to 2 ins.

No further tests of the pipe were made, nor were they considered necessary, it having been shown by those already made that the

conditions under which the pipe had been laid had not been injurious.

The conclusion reached at the time, as the result of the foregoing tests, was that some degree of compression of the pipe might be expected with all sizes and weights of plate in use on the line; that this compression could not be entirely avoided without considerably increasing the cost of the work; and that if this compression did exist, it would not injure the pipe.

When the work of pipe laying was resumed in the spring of 1894, additional inspectors were employed, and the work of back-filling was closely watched for the purpose of securing a strict compliance with the specifications, which provided that below the upper surface of the pipe the earth must be tamped in layers not exceeding 6 ins. in thickness.

In order to have some further practical evidence as to the cost and effect of properly doing the work of back-filling, a point on the 42-in. pipe laid the previous year was selected where a flattening of the top varying from $1\frac{5}{8}$ to $2\frac{3}{4}$ ins. was known to exist.

One hundred feet of this pipe was then uncovered, the inside diameter of the small courses being carefully measured, both before and after the earth was removed. The record shows that the pipe expanded vertically from $\frac{1}{4}$ to $1\frac{5}{8}$ ins. as soon as it was uncovered.

The earth from the trench, principally yellowish clay and sand, was then carefully tamped around and over the pipe. Below the top of the pipe one man used a tamping bar for each man with a shovel. For the remainder of the trench, one tamping bar was used to three shovels. The cost of back-filling for this short section was 9 cents per cubic yard of the original trench excavation. Measurements taken when the pipe had been covered again, showed a vertical compression of but $\frac{1}{8}$ in. during the process of refilling and tamping.

In this connection mention may be made of a point on the 35-in. pipe where the flattening of the top was found to reach a maximum of 3 ins. when measured in February, 1894. During an inspection of the pipe line in June, 1896, this section was measured again and the flattening was found to be from $\frac{1}{2}$ in. to 2 ins. The trench was excavated in sandy clay soil, the pipe covering ranging from 4 to 5 ft. in depth. When the last measurement was taken, the pipe had been subjected to a hydraulic pressure of 60 lbs. per square inch for sixteen months.

The foregoing notes are presented with the thought that possibly they may be of service to some seeker after light upon the question of the depth of trench permissible for steel water pipe under certain conditions. Such information was not available to the author at the time the grades for the Bull Run pipe line were decided upon. At one summit a cut of from 12 to 16 ft. was required for a distance of 1 500 ft. Under the circumstances it was necessary that the trench should be entirely refilled, and, in order to avoid an excessive loading of the pipe, an expense of $1 500 was incurred in grading off the entire width of the right-of-way road, so that the pipe covering would not exceed a maximum depth of 7 ft. This would not be done again under similar circumstances.

A detailed statement of measurements taken appears in the following tables :

Riveted Steel Pipe; 29 Ft. 3 Ins. Long, 33 Ins. Diameter, No. 6 Plate, B. W. G.

Test No. 1.

	5 Ft. from End.		Center.		5 Ft. from End.	
	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.
Pipe in place, unloaded	......	......	$32\frac{3}{4}''$	$32\frac{11}{16}''$	......	......
Sand tamped around pipe, $5\frac{5}{8}$ ft. deep on top	$32\frac{3}{4}''$	$33''$	$32\frac{3}{8}''$	$33\frac{1}{4}''$	$32\frac{9}{16}''$	$33\frac{3}{16}''$
After standing 40 hours	$32\frac{3}{4}''$	$33\frac{1}{8}''$	$32\frac{3}{8}''$	$33\frac{3}{8}''$	$32\frac{9}{16}''$	$33\frac{1}{4}''$
Compression	......	......	$\frac{3}{8}''$	......	......	......
Pipe unloaded	$33''$	$32\frac{7}{8}''$	$32\frac{3}{4}''$	$33''$	$32\frac{7}{8}''$	$33''$
Expansion	......	......	$\frac{3}{8}''$	......	......	......

Test No. 2.

Pipe unloaded	$33''$	$32\frac{7}{8}''$	$32\frac{3}{4}''$	$33''$	$32\frac{7}{8}''$	$33''$
Sand $5\frac{5}{8}$ ft. deep, loosely piled	$32\frac{11}{16}''$	$33\frac{1}{8}''$	$32\frac{3}{8}''$	$33\frac{7}{16}''$	$32\frac{5}{8}''$	$33\frac{1}{4}''$
Compression	$\frac{5}{16}''$	......	$\frac{3}{8}''$	.	$\frac{1}{4}''$	......
Pipe unloaded	$33''$	$32\frac{13}{16}''$	$32\frac{3}{4}''$	$33''$	$32\frac{7}{8}''$	$32\frac{15}{16}''$
Expansion	$\frac{5}{16}''$	......	$\frac{3}{8}''$	......	$\frac{1}{4}''$	......

Test No. 3.

Pipe unloaded and braced outside	$33\frac{1}{8}''$	$32\frac{5}{8}''$	$32\frac{7}{8}''$	$32\frac{13}{16}''$	$32\frac{15}{16}''$	$32\frac{13}{16}''$
Pipe loaded, sand $5\frac{5}{8}$ ft. deep	$32\frac{3}{4}''$	$33''$	$32\frac{7}{16}''$	$33\frac{1}{4}''$	$32\frac{5}{8}''$	$33\frac{3}{16}''$
Compression	$\frac{3}{8}''$	......	$\frac{7}{16}''$	......	$\frac{5}{16}''$	......
Pipe unloaded	$33\frac{1}{16}''$	$32\frac{3}{4}''$	$32\frac{3}{4}''$	$33''$	$32\frac{7}{8}''$	$32\frac{7}{8}''$
Expansion	$\frac{5}{16}''$	......	$\frac{5}{16}''$	......	$\frac{1}{4}''$	......

Riveted Steel Pipe, 29 Ft. 3 Ins. Long, 42 Ins. Diameter, No. 4 Plate, B. W. G.

Test No. 4.

	Small Plate End.		5 Ft. from End.		Center.		5 Ft. from End.		Large Plate End.	
	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.
Pipe in place, unloaded.	$41\frac{1}{2}''$	$42\frac{1}{4}''$	$41\frac{7}{16}''$	$42\frac{3}{8}''$	$41\frac{9}{16}''$	$42\frac{3}{16}''$	$41\frac{1}{4}''$	$42\frac{1}{2}''$	$41\frac{13}{16}''$	$42\frac{13}{16}''$
Sand tamped around pipe, 5¼ ft. deep on top	$41\frac{1}{4}''$	$42\frac{1}{2}''$	$41\frac{1}{16}''$	$42\frac{13}{16}''$	$41\frac{3}{16}''$	$42\frac{5}{8}''$	$40\frac{13}{16}''$	$42\frac{7}{8}''$	$41\frac{1}{2}''$	$43\frac{3}{16}''$
Compression	$\frac{1}{4}''$	......	$\frac{3}{8}''$	......	$\frac{3}{8}''$	......	$\frac{7}{16}''$	. . .	$\frac{5}{16}''$	
Pipe unloaded	$41\frac{1}{2}''$	$42\frac{1}{4}''$	$41\frac{7}{16}''$	$42\frac{7}{16}''$	$41\frac{5}{8}''$	$42\frac{3}{16}''$	$41\frac{1}{4}''$	$42\frac{1}{2}''$	$41\frac{3}{4}''$	$42\frac{13}{16}''$
Expansion	$\frac{1}{4}''$	......	$\frac{3}{8}''$	......	$\frac{7}{16}''$	......	$\frac{7}{16}''$	.....	$\frac{1}{4}''$	

Test No. 5, 42-In. Pipe, No. 6 Plate, B. W. G.

Pipe in place, unloaded.	$41\frac{3}{8}''$	$42\frac{3}{8}''$	$41\frac{7}{16}''$	$42\frac{5}{16}''$	$41\frac{11}{16}''$	$42\frac{1}{8}''$	$41\frac{1}{4}''$	$42\frac{1}{2}''$	$41\frac{7}{8}''$	$42\frac{11}{16}''$
Sand tamped around pipe, 5¼ ft. deep on top	$40\frac{15}{16}''$	$42\frac{13}{16}''$	$40\frac{7}{8}''$	$42\frac{3}{4}''$	$41\frac{3}{16}''$	$42\frac{5}{8}''$	$40\frac{11}{16}''$	$43''$	$41\frac{3}{8}''$	$43\frac{3}{16}''$
Compression	$\frac{7}{16}''$	......	$\frac{9}{16}''$	......	$\frac{1}{2}''$	......	$\frac{9}{16}''$	......	$\frac{1}{2}''$	
Pipe unloaded	$41\frac{3}{8}''$	$42\frac{5}{16}''$	$41\frac{1}{2}''$	$42\frac{3}{16}''$	$41\frac{3}{4}''$	$42\frac{1}{16}''$	$41\frac{3}{8}''$	$42\frac{7}{16}''$	$41\frac{7}{8}''$	$42\frac{5}{8}''$
Expansion	$\frac{7}{16}''$	......	$\frac{5}{8}''$	......	$\frac{9}{16}''$	......	$\frac{11}{16}''$	......	$\frac{1}{2}''$	

Test No. 6.

Pipe unloaded, braced outside, 7½ ft. centers	$41\frac{3}{4}''$	$42\frac{1}{16}''$	$41\frac{15}{16}''$	$41\frac{13}{16}''$	$42\frac{5}{16}''$	$41\frac{1}{4}''$	$41\frac{7}{8}''$	$41\frac{7}{8}''$	$42\frac{3}{8}''$	$42\frac{1}{4}''$
Sand tamped around pipe load	$41\frac{5}{16}''$	$42\frac{3}{8}''$	$41\frac{1}{2}''$	$42\frac{3}{16}''$	$41\frac{7}{8}''$	$41\frac{1}{4}''$	$41\frac{7}{16}''$	$42\frac{1}{4}''$	$42\frac{1}{16}''$	$42\frac{1}{2}''$
Compression	$\frac{7}{16}''$	......	$\frac{7}{16}''$	......	$\frac{7}{16}''$	......	$\frac{7}{16}''$	......	$\frac{5}{16}''$	
Pipe unloaded and braces removed	$41\frac{3}{8}''$	$42\frac{3}{8}''$	$41\frac{1}{2}''$	$42\frac{1}{4}''$	$41\frac{3}{4}''$	$42\frac{1}{16}''$	$41\frac{3}{8}''$	$42\frac{3}{8}''$	$42''$	$42\frac{5}{8}''$
Expansion	$\frac{1}{16}''$	......	0							

Test No. 7.

Pipe in place, unloaded.	$41\frac{3}{8}''$	$42\frac{5}{8}''$	$41\frac{1}{2}''$	$42\frac{1}{4}''$	$41\frac{3}{4}''$	$42\frac{1}{16}''$	$41\frac{3}{8}''$	$42\frac{3}{8}''$	$42''$	$42\frac{5}{8}''$
Platform loaded with 4 800 lbs. iron placed on top of pipe. Sides unsupported	$40\frac{15}{16}''$	$42\frac{3}{4}''$	$40\frac{15}{16}''$	$42\frac{11}{16}''$	$41\frac{3}{16}''$	$42\frac{1}{2}''$	$40\frac{3}{4}''$	$42\frac{15}{16}''$	$41\frac{3}{8}''$	$43\frac{1}{8}''$
Weight increased to 17 000 lbs	$40\frac{5}{16}''$	$43\frac{3}{8}''$	$40\frac{3}{16}''$	$43\frac{1}{2}''$	$40\frac{3}{16}''$	$43\frac{5}{8}''$	$39\frac{3}{4}''$	$43\frac{15}{16}''$	$40\frac{7}{16}''$	$44''$
Compression	$1\frac{1}{16}''$	......	$1\frac{5}{16}''$	......	$1\frac{9}{16}''$	......	$1\frac{5}{8}''$	......	$1\frac{9}{16}''$	
Pipe unloaded	$41\frac{3}{8}''$	$42\frac{3}{8}''$	$41\frac{7}{16}''$	$42\frac{5}{16}''$	$41\frac{5}{8}''$	$42\frac{1}{8}''$	$41\frac{1}{4}''$	$42\frac{1}{2}''$	$41\frac{13}{16}''$	$42\frac{3}{4}''$
Expansion	$1\frac{1}{16}''$	......	$1\frac{1}{4}''$	......	$1\frac{7}{16}''$	......	$1\frac{1}{2}''$	......	$1\frac{3}{8}''$	

Pipe subjected to hydrostatic pressure of 150 lbs. per square inch. No leaks found.

TEST NO. 8, 42-IN. PIPE, NO. 6 PLATE, B. W. G.—(*Continued*).

	Small Plate End.		5 Ft. from End.		Center.		5 Ft. from End.		Large Plate End.	
	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.
Pipe in place, unloaded.	41 5/16"	42 3/8"	41 7/16"	42 1/4"	41 11/16"	42 1/8"	41 1/4"	42 1/2"	41 7/8"	42 11/16"
Box filled with sand, weight, 36 000 lbs. placed on top of pipe. Sides unsupported...	38 11/16"	44 3/4"	38 1/16"	45 1/8"	37 9/16"	45 13/16"	37 11/16"	46 3/8"	37 1/2"	46 1/2"
After standing 40 hours	38 11/16"	44 13/16"	37 15/16"	45 1/8"	37 1/2"	45 7/8"	36 9/16"	46 1/8"	37 3/8"	46 9/16"
Compression.	2 5/8"	......	3 1/2"	......	4 3/16"	......	4 11/16"	......	4 1/2"	
Pipe unloaded.........	41 3/16"	42 9/16"	41 3/16"	42 7/16"	41 7/16"	42 3/8"	41"	42 13/16"	41 1/2"	42 15/16"
Expansion.............	2 1/2"	......	3 1/4"	......	3 15/16"	......	4 7/16"	......	4 1/8"	
Apparent set.....	1/8"	......	1/4"	......	1/4"	......	1/4"	......	3/8"	

TEST NO. 9.

Pipe in place, unloaded.	41 3/16"	42 9/16"	41 3/16"	42 7/16"	41 7/16"	42 3/8"	41"	42 13/16"	41 1/2"	42 15/16"
Sand tamped around pipe 5 1/4 ft. deep on top	40 11/16"	43"	40 1/2"	43"	40 3/4	43 1/16"	40 1/4"	43 3/8"	40 15/16"	43 1/2"
Sand saturated with water	40 7/16"	43 1/4"	40 1/4"	43 3/16"	40 1/2"	43 1/4"	40"	43 9/16"	40 11/16"	43 3/4"
Compression............	3/4"	......	15/16"	......	15/16"	......	1"	......	13/16"	
Pipe unloaded.........	41 3/16"	42 1/2"	41 3/16"	42 7/16"	41 1/2"	42 3/8"	41"	42 3/4"	41 9/16"	42 7/8"
Expansion.............	3/4"	......	15/16"	......	1"	......	1"	......	7/8"	

Pipe subjected to hydrostatic pressure of 150 lbs. per square inch. No leaks found.

TEST NO. 10.

Pipe in place, unloaded...............	41 1/4"	42 7/16"	41 1/4"	42 3/8"	41 1/2"	42 5/16"	41"	42 3/4"	41 9/16"	42 15/16"
Estimated weights applied by means of jack screws at points 1, 2 and 3.............	......	......	13 390	lbs.	14 190	lbs.	15 170	lbs		
Pipe then measured ..	33 3/4"	48 7/8"	33 1/16"	48 1/4"	32 13/16"	48 15/16"	32 1/4"	49 15/16"	33 1/16"	49 13/16"
Compression	7 1/2"	......	8 3/16"	......	8 11/16"	......	8 3/4"	......	8 1/2"	
Pipe unloaded after 24 hours.....	38 7/16"	45 3/16"	38 5/8"	45 1/4"	38 13/16"	45 3/8"	38 7/16"	45 7/16"	38 3/4"	45 1/2"
Expansion......	4 11/16"	......	5 9/16"	......	6"	......	6 3/16"	......	5 11/16"	
Apparent set..........	2 13/16"	......	2 5/8"	......	2 11/16"	......	2 9/16"	......	2 13/16"	

Pipe subjected to hydrostatic pressure of 150 lbs per square inch. No leaks found.

After removing from hydrostatic pressure.	39 9/16"	44"	39 3/4"	44 1/4"	39 7/8"	44 5/16"	39 1/4"	44 1/8"	39 7/8"	44 1/2"
Permanent set.........	1 13/16"	......	1 11/16"	......	1 13/16"	......	1 3/4"	......	2"	

MEASUREMENTS OF 42-IN. PIPE, NO. 6 PLATE, IN TRENCH.

	COVERED.		UNCOVERED		AGAIN COVERED.	
	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.
Station 1 320 + 20	39¾"	43⅝"	40"	44"	40"	44"
" " + 30	40⅛"	43¾"	41"	43⅛"	40⅝"	43¼"
" " + 40	39¾"	43⅝"	41⅛"	42⅝"	41"	42¾"
" " + 50	40⅛"	43¾"	41⅜"	42¾"	41¼"	42⅞"
" " + 60	39¼"	44⅛"	40⅞"	43⅛"	40¾"	43¼"
" " + 70	39⅝"	43¾"	41⅛"	42¾"	41"	42⅞"
" " + 80	39⅞"	43⅝"	41⅛"	42¾"	41"	42⅞"
" " + 90	40⅜"	43½"	41⅛"	42½"	41⅛"	42⅞"
" 1 321 + 00	39¾"	44"	41"	43"	40⅞"	43⅛"
" " + 10	40⅛"	43½"	40⅝"	43¼"	40½"	43¼"
" " + 20	39½"	43¼"	40⅞"	43"	40⅞"	43"

DISCUSSION.

Mr. Green.

BERNARD R. GREEN, M. Am. Soc. C. E.—Compression of a riveted pipe under the filling of a trench cannot continue beyond a certain degree, provided there has been a fair amount of tamping of the filling beneath and beside the pipe. Distortion is evidently caused by the downward settlement of the earth upon the pipe, which must be resisted by the earth at the sides. The deformation will naturally be limited by the amount of side pressure produced by the side tamping, and if this be sufficient—probably very difficult to accomplish—there will be no yielding laterally, and, consequently, no distortion of the pipe. Even neglecting the natural arching effect in the settlement of the filling in a trench, the side tamping might without much trouble be made sufficient to preserve the pipe from serious injury, although not quite enough to save it from some deformation. Hence it is unnecessary to grade away to relieve the pressure due to back-filling.

Mr. Nichols.

O. F. NICHOLS, M. Am. Soc. C. E.—It appears that in all the experiments noted in the paper, the elasticity of the metal was sufficient to restore the pipes nearly or quite to their original form after the load was removed. In one of the tests, in which the distortion had been $1\frac{5}{8}$ ins., the pipe went back to within $\frac{1}{2}$ in. of its original diameter, and in another case, where the distortion was over 8 ins., the permanent set was $1\frac{5}{8}$ ins. In a large pipe it would be practicable and proper to use vertical studding and retain it until the side-filling was tamped and the back-filling in place. The distance between the struts would naturally depend on the thickness of the plate, or a line of stringers along the top of the pipe might be used as caps, enabling the struts to be spaced farther apart. When the filling material is well tamped 4 or 5 ft. deep, and of a character to arch somewhat in the trench, the pressure on the pipe will be somewhat less than that obtained by a mass of sand of the same depth confined in a box with smooth sides, which allow the full weight to come directly on the pipe. In this respect the tests were probably more severe than the conditions in an ordinary trench without sheeting. The fact that the thin pipe resumed its original shape and did not leak after these tests is conclusive proof that it can be used without jeopardizing the safety of the conduit. If the pipe is thick enough to withstand handling and laying without injury, no trouble need be feared when it is in use under pressure except such as may be due to corrosion. The pipe described in the paper seems to be made of very thin plates when the danger of oxidation is considered, and it is a question whether a riveted pipe, like cast-iron pipe, should not be made thicker than theoretical requirements call for in order to make provision against rusting.

Mr. Nichols. In tamping about a pipe it might be well to adopt the old plan of wetting the material thoroughly. The success of this method of working depends somewhat on the material, being possibly greater with sand than loamy earth, and if the plan is not prohibited for other reasons, it might be very effective and economical where an abundant supply of water is available.

Mr. Goldmark. HENRY GOLDMARK, M. Am. Soc. C. E.—If a pipe shows so complete a recovery from distortion as the sections which were tested, it needs little reflection to show that damage is out of the question. The back-filling below the lower half of the pipe is that liable to cause the most trouble and is the most difficult to inspect thoroughly. The trench is made as narrow as possible, and it is almost impossible in some cases to get room enough to do proper tamping by hand. If sand or similar material free from lumps were always available for use in all the small crevices beneath the pipe, there would be less trouble, but with the poorer material which must often be employed, tamping becomes more difficult. For this reason some studies were made in connection with a work on which the speaker was recently engaged to devise a machine to tamp the triangular spaces under the pipe, close to the ground, in a better manner than ramming by hand with shovels or small tamps. A sort of linkage, a rather heavy frame traveling on top of the pipe, was finally built and used with some success, experimentally, although it might have proved more expensive in regular service than the old method of work. By the time the draftsman had planned a complete apparatus, the contractor had succeeded in back-filling almost the entire trench, so that it did not have a trial. Still, it is probable that a tamping machine operated by compressed air, or some other means usually at hand where such pipes have to be riveted, might be devised by which the material below the bottom third of the pipe could be rammed more satisfactorily than it is ever done by hand. Deformation is almost invariably accompanied by an increase in the horizontal diameter of the pipe, and if this increase is rendered impossible by heavy ramming, there will probably be no distortion of the pipe.

Mr. Tuttle. A. S. TUTTLE, Assoc. M. Am. Soc. C. E.—That precautions against excessive deformation or even total collapse of steel pipe subjected to external pressure have often been taken is shown by the stipulations requiring the attachment of stiffening rings around the outside of the pipe at points where unusual weights are to be supported, which are found in the specifications for the 38-in. steel pipe, $\frac{1}{4}$ to $\frac{3}{8}$ in. thick, for Rochester; the 48-in. steel pipe, $\frac{5}{16}$ in. thick, for New Bedford; the 60-in. steel pipe, $\frac{1}{2}$ in. thick, for Allegheny; and the 60-in. and 66-in. steel pipe, $\frac{5}{16}$ to $\frac{3}{8}$ in. thick, for Brooklyn.

In the latter city two rings, of 4 x 4 x $\frac{3}{8}$-in. steel angles, weighing 15.7 lbs. per foot, will be required per plate (78-in.) throughout the

right of way of all road crossings, and wherever the fill over the top of the pipe exceeds 6 ft. Mr. Tuttle.

The effect of external load is liable to be further increased in a steel pipe operated under pressure, by the possible existence of a partial vacuum, caused either by improperly opening a blow-off or by rupture of the pipe. The tests made by the author are of great interest in exhibiting the ability of the pipe to sustain external pressures without leakage, and particularly after such excessive distortion as was obtained in the test described as No. 10. It is to be regretted that the position of the seams is not stated.

Clemens Herschel, M. Am. Soc. C. E.—The behavior of riveted pipe when subjected to back-filling is no new thing, for it has been under observation for forty or fifty years in mill practice, and with pipes up to 12 ft. in diameter. These are put in the trench, temporarily braced with joists on the inside, and after the earth is once filled around them no one ever thinks anything more about their becoming distorted or bending, although pipes of so large a diameter with metal only $\frac{3}{8}$ in. thick appear very limber above ground. Riveted pipe will endure treatment that few would consider it capable of withstanding. In long lengths it is very flexible, while yet remaining tight. Take, for example, a lead pencil. It is stiff in short pieces, and apparently cannot be bent at all without breaking. But a pencil 20 ft. long could be bent into a hoop without difficulty. It is the same with a riveted pipe. Such a pipe 4 ft. in diameter, though stiff in short lengths, can be bent to a radius of 1 200 or 1 500 ft. and remain perfectly tight. In laying seven lines of 16-in. lap-welded pipe under the river at Belleville, N. J., advantage was taken of this fact. A trench was dredged in the bed of the river and the pipes were pulled across on the bed, being tested by compressed air as they were hauled over. The first line was not completed until two accidents had occurred, owing to the fact that the ditch had not been graded to a suitable radius where it left the shore and went under water. But after these two unsuccessful attempts, no further trouble was experienced, and in this manner seven lines of pipe were laid without interfering with passing vessels, which would have made any other plan difficult of execution. Mr. Herschel.

Reinforcement rings have not been used to any great extent on the speaker's work, for it was found difficult to keep them water-tight around the rivet holes that fasten them to the main pipe. A better method of giving the desired strength at load points, in the speaker's opinion, is to encase the pipe in concrete, and, if necessary, to put rails or beams over the pipe in the concrete.

CORRESPONDENCE.

Mr. Bush. H. D. Bush, M. Am. Soc. C. E.—The paper seems to call for discussion by the writer, who was engineer and superintendent on the Bull Run pipe line for the contractors who did not properly tamp the earth around the pipe when the back-filling of the trench was being done. In January, 1894, the writer, in going through the pipe in company with an employee, noticed the flattening of a section of 42-in. pipe of No. 6 B. W. G. thickness in a trench 10½ ft. deep. This was reported to the chief engineer by the writer. The discovery was made on that portion of the line where the whole right-of-way road was graded to reduce the cut to 10½ ft., so that the pipe covering would not exceed the maximum depth of 7 ft. The writer knows of no places in the 35-in. pipe where the flattening was noticeable to the eye. If any flattening was discovered by careful measurement, it was no indication of careless tamping of the earth around the pipe. The tamping in 1893, as in 1894, was done to the satisfaction of the assistant engineers and inspectors employed to look after it. The facts are as follows:

The excessive flattening of the 42-in. No. 6 pipe occurred in a trench 10½ ft. deep, the bottom of which was, as stated by the author, 12 to 16 ft. below the original surface of the ground. Neighboring farmers' wells were only 8 to 10 ft. deep, and there was an immense volume of water in this portion of the trench. The work was done during the almost incessant rain of an Oregon winter, and the material with which the trench was refilled was almost slush. Even the dryest material would have soon become saturated with water and partly washed away from under the pipe in this location.

The 35-in. pipe put down in 1893 was through a rough country, the line crossing many small water-courses, and having short, comparatively steep grades. The heavy rains, soaking through the ground, naturally ran down these grades under the pipe, loosening, and to some extent washing away, the filling around them.

On some portions of the line put down in 1894, wooden drain boxes, 4 x 4 ins. inside section, made of two 1 x 4-in. and two 1 x 6-in. boards, were placed in the bottom of the trench below the level of the bottom of the pipe, at the suggestion of the writer. These boxes ran from joint hole to joint hole, and the joint holes below the pipe were filled with broken stone. While these boxes helped the contractors during construction, the chief engineer believed, with the writer, that they would serve to carry away the water which would otherwise run along the pipe and gradually undermine it.

The controversy concerning the tamping of the earth around and over the pipe was a serious matter to the contractors. The specifications called for tamping in 6-in. layers below the top of pipe, as stated by the author. Above this level, a separate clause in the specifications called for careful tamping, and said nothing about layers of any thickness. The meaning clearly was that less care need be taken with the tamping above the pipe than below and around it. On that portion of the line finished during the summer of 1893, the upper portion of the trench, after the pipe had about 1 ft. of earth on it, was refilled with teams and drag scrapers. The runways coming down into the trench were 30 to 40 ft. apart, and the passing of a team of horses, scraper and driver from seven to ten times over the earth already in place, for each cubic yard refilled, furnished, to the writer's mind, the best kind of tamping. Mr. Bush.

When work began in 1894, the engineers, who had allowed refilling by scrapers in 1893, said it must be done by hand with one tamper to each two shovelers for the upper portion of the trench. Afterwards, one tamper to three shovelers was the ratio permitted for the upper portion of trench, and the work generally cost considerably more than the 9 cents a yard for the whole amount of excavation (a certain surplus was never refilled), as stated by the author. The work could have been done for less money with teams and scrapers, and the writer believes that the tamping would have been much better than that done with the light wooden tamping sticks used and permitted by the engineers in charge of the work.

The excuse given for not allowing the use of horses was that the weight of the team over the pipe would injure it, though experiments made by the writer failed to show any change in the vertical diameter of the pipe when teams were driven over it after the earth had been refilled and tamped in the usual way to a level of a foot or less over the top of the pipe. The absurdity of this excuse may be seen from Test 5, on a pipe of the largest diameter, 42 ins., and thinnest plate, No. 6. This pipe was loaded with a weight of 420 lbs. per square foot, or 1 470 lbs. per linear foot, with an average depression of $\frac{1}{2}$ in. and no permanent set. Moreover, the portion of the line on which the contractors wished most to use horses for refilling the upper portion of the trench was on a stretch of about six miles of 33-in. pipe. This pipe, according to Test 1, showed practically no deflection under a load of 460 lbs. per square foot after forty hours.

The paper is of value in showing that the harsh treatment of some of the pipes in the tests produced no leaks in the shop work. If every section of riveted pipe used could be shop tested and made tight under its working pressure, and afterwards handled with ordinary care, the worst trouble in handling such pipe in the field could be

Mr. Bush. avoided. On the Bull Run pipe line, as fast as the pipe was laid, the trench, except the joint holes, was refilled and tamped to a level of about 1 ft. over the top of the pipe.

On the Allegheny 60-in. line, on which the writer was engaged in 1895, and on the 48-in. New Bedford Line, which he laid in 1897, and generally in the East, the practice is to lay, rivet, caulk, and leave exposed for testing a length of about 2 000 ft. of pipe. With the extremes of temperature during the summer, the expansion and contraction of such a length of uncovered pipe is considerable. Moreover, the top of the pipe gets much hotter than the bottom which rests on the bottom of the trench. The unequal and considerable contraction and expansion makes it hard to get good riveting. Holes that are good in the morning are half blind in the afternoon, and *vice versa.* When riveted pipes are at once covered with earth as fast as laid, except at the joint holes, they are held firmly in line, and at a comparatively even temperature. Any leak in shop work that may have been overlooked will show itself in the joint holes when the whole line is tested. If the shop work has once been tight, it should remain so; and the author's report of tests made in Portland may give additional assurance of this fact.

Mr. Searles. W. H. Searles, M. Am. Soc. C. E.—The experiments upon flexible pipe detailed in this paper are interesting to the writer, as they are along the line of investigations which he had occasion to make some three years ago. Desiring to know at that time what amount of depression would be permissible in the crown of a certain steel pipe, and what load would produce it, the pipe being not yet built, he made some experiments upon flexible rings, and, generalizing upon the results, he derived certain formulas and tables applicable to any case of the kind. These appeared in a paper* by the writer, in which it was shown that, in the case of a flexible ring in a vertical plane, loaded at the crown and unsupported at the sides, the relation of the vertical and horizontal diameters to each other under varying load is that of the co-ordinates of a common parabola, the axis of which is inclined to the horizontal diameter of an angle of 42° 33′ 38″. It is also shown that the relation between the amount of depression, in inches, and the load producing it, drawn to an assumed scale of inches, is that of the coordinates of a hyperbola, whether the loads are positive or negative or change from one to the other. The same paper gives the principal moments, the radii of curvature at the principal points, and also the location of the point of no moment on the ring at any stage of distortion. The tables give a series of values of all these qualities for a typical ring or section of pipe in which the mean radius is unity, and the product of EI also unity; so that for a pipe of any other radius and value of EI, the desired results are to be obtained therefrom by

* See the *Journal* of the Association of Engineering Societies, Vol. xv, p. 124.

simple multiplication. The letter E represents the modulus of elasticity of the material, and I the moment of inertia, not of the annular section, but of a longitudinal section through one side of the pipe. Mr. Searles.

The following is a specimen of one table in compression, by which some of the author's tests may be investigated: ΔY is the crown depression or the shortening of the radius, and in terms of radius; ΔX is the side extension of one side in terms of R; K is the half load in pounds, for $R = 1$ and $E\,I = 1$; A B are the bending moments at the side and top; R_a R_b are the radii of curvature in terms of the radius R.

TABLE.

ΔY	K	ΔX	A	B	R_a	R_b
—	+	+	+	+	+	+
.00	.0	.0	.0	.0	1	1
.01	.06607	.00910	.02423	.04244	.97639	1.04433
.02	.12998	.01803	.04808	.08424	.95412	1.09199
.03	.19187	.02679	.07159	.12542	.93319	1.14341
.04	.25190	.03539	.09477	.16604	.91343	1.19909
.05	.31017	.04383	.11765	.20612	.89473	1.25963

Having ascertained R, E and I in any case, the half-load P at the crown is found by

$$P = K\frac{2\,E\,I}{R^2} \;\therefore\; K = \frac{P\,R^2}{2\,E\,I}$$

To find the principal moments multiply A and B of the table by $\frac{E\,I}{R}$.

To find the radius of curvature, multiply R_a or R_b of the table by the original mean radius R.

The depressions in Test 7*a*, the first one made with a concentrated load, may be computed as follows: The average internal diameter of this specimen was 41.874, half of which, plus one thickness of No. 6 plate, 0.203, is the mean radius, $R = 21.14$. The load per lineal foot is found to be 164.10 lbs.; and for 1 ft. in length the moment of inertia $I = \frac{b\,d^3}{12} = d^3 = (0.203)^3 = 0.0083654$.

Assuming $E = 30\,000\,000$,

$$K = \frac{P\,R^2}{2\,E\,I} = 0.07312.$$

Mr. Searles. Referring to the table, it will be seen that the corresponding value of $\varDelta Y$ must be between 0.01 and 0.02, and by interpolation $\varDelta Y = .01182$. Multiplying by $2R$ gives the compression of diameter............... 0.50 in.

The test gives for first load of 4 800 lbs.................. 0.625 "

Difference.................. —0.125 in.

Finding $\varDelta X$ by interpolation, the extension of diameter is.. 0.458 in.

The test gives.................................... 0.438 "

Difference.................. +0.020 in.

In Test 7*b*, with a load of 17 000 lbs.:

Load per lineal foot........................	$2P =$	581.20 lbs.
By formula..................................	$K =$	0.2590 "
By interpolation............................	$\varDelta Y =$	0.0412
Depression of diameter......................		1.743 ins.
Test..		1.438 "
Difference..........	+	0.305 in.
Extension of diameter.......................		1.540 ins.
Test..		1.375 "
Difference..........	+	0.165 in.

In Test 8 the pipe was measured just after loading and again forty hours later; considering these as two tests 8*a* and 8*b*, with a load per lineal foot of 1 230.74 lbs., $K = 0.5484$; $\varDelta Y = 0.0940$.

a. Compression,	3.976;	Test, 3.545;	difference,	+ 0.431
b. "	3.976;	" 3.900;	"	− 0.076
a. Extension,	3.769;	" 3.625;	"	+ 0.144
b. "	3.769;	" 3.660;	"	+ 0.109

In Test 10—

Load per lineal foot, 1 461.54 lbs.

$K = 0.65127$; $\varDelta Y = 0.1157$.

Comp. diam., 4.8941; Test, 8.3125; difference — 3.4184.

Extension, 4.049; " 6.600; " — 2.551.

The wide divergence in this case indicates that the metal is strained beyond its elastic limit, and this may be easily proved. The formula for extreme fiber stress at the crown is—

$$p = \frac{B\,E\,d}{2\,R}$$

in which B is taken from the table, d is the thickness of metal, and R

is the original mean radius. For the present value of $\Delta Y = 0.1157$, Mr. Searles.
$B = 0.4561$ and $d = 0.203$; hence the fiber strain $p = 65\ 666$ lbs.

In the Test 7*a*, $p = 7\ 222$ lbs.
" " 7*b*, $p = 24\ 604$ "
" " 8, $p = 54\ 255$ "

As in Test 8 the discrepancies between theory and experiment are small, the conclusion is that a fiber stress of 50 000 lbs. at the crown is not inconsistent with safety; the fiber stress at the side never exceeds 60% of that at the crown, and between the two points there is a point where the bending moment is zero.

The differences shown are not as small as might be desired, but it will be noticed that they are less than the difference in measured compressions at different points of the same pipe under the same loading. Moreover, in the several tests some differences are plus and some minus, so that on the whole the average agreement is quite close.

The relative effects of concentrated or crown loading and uniform loading have not been investigated. With distributed load the sides of the pipe receive some support and so modify the conditions. Comparing Test 9 with the first loading in Test 7, it will be seen that the average depression was the same, viz., $\frac{7}{8}$ in., while the concentrated load was about 70% of the uniform load. This is a little larger than the five-eighths, or $62\frac{1}{2}\%$ recognized as correct in the case of beams, whereas it would seem as though the truth would be nearer 50%, owing to the side support obtained, not to mention the relief of weight afforded by the friction of the sides of the ditch above the pipe. When the back-filling is thoroughly tamped, the load may be limited by the arching of the material, and so kept within safe limits, however deep the trench may be.

To cite another instance, a cast-iron culvert 6 ft. in diameter was built in the city of Cleveland and covered with an embankment of earth from 60 to 70 ft. high. The castings were 1.9 ins. thick. The pipe was laid in a bed of concrete 9 ft. wide, and carried up on each side of the pipe to the level of the center, where it was 9 ins. thick each side. The embankment was made in layers, the first of which are supposed to have been tamped. Some time after the work was finished, four contiguous lengths of pipe, 32 ft. in all, were found to be cracked longitudinally top and bottom, and the difference in vertical and horizontal diameters amounted to 4 ins.*

The investigation of this case would be as follows: For cast-iron take rupture by tension at 16 000 lbs. $= p$, and $E = 16\ 000\ 000$. The mean radius $R = 36.95$; $d = 1.90$; $I = d^3 = 6.895$ for a length of 1 ft.

* The details are more particularly described by W. P. Rice, M. Am. Soc. C. E., in a paper in the *Journal* of the Association of Engineering Societies, Vol. xvi, p. 79.

Mr. Searles. Under condition of incipient rupture at the crown, the tabular moment is—

$$B = \frac{p}{E} \quad \frac{2\,R}{d} = 0.0389.$$

Hence by the table $\Delta\ Y = 0.00917$ and $K = 0.06059$. Then

$$P = \frac{2\,E\,I\,K}{R^2} = 9\,740.7 \text{ lbs.}$$

$2\ P = 19\,481.4$ = breaking crown load per linear foot.

$4\ P = 38\,963$ = distributed breaking load per linear foot.

The pipe being 6.33 ft. wide outside, the breaking load per square foot would be 6 155 lbs.; and taking the weight of earth at 110 lbs. per cubic foot, the height of the prism above pipe would be 56 ft. Adding 6 ft. for the diameter of the pipe it appears that the weight of an embankment 62 ft. high would be sufficient to rupture the pipe. The assumption of vertical sides or slopes for the earth prism is a compromise between the slopes of a new embankment which would diverge upward from the pipe, and those of an old settled bank which would converge upward.

The tabular depression of the crown, 0.00917, multiplied by 2 R, gives 0.67 in. as the compression of the vertical diameter, and since the extension of the horizontal diameter would be about the same, the difference of diameters would be 1.34 ins. at the point of incipient rupture. As the measured difference was 4 ins., the parts must have settled after rupture. As the crack exists at the bottom as well as the top, it is evident that the concrete failed as an abutment, and it is probable that the pipe developed outside cracks at the sides, which, however, did not show internally, owing to the great pressure.

As only 32 ft. of the pipe cracked out of several hundred in the total length, the inference is that the actual load was not greatly in excess of the breaking load. The same inference would be drawn from the depth of 62 ft. computed above, compared with the actual depth, which was less than 70 ft.

Mr. Clarke. D. D. Clarke, M. Am. Soc. C. E.—It was not the purpose of the author to introduce into his paper any discussion of the relations, harmonious or otherwise, which sometimes exist between engineers and contractors, and he regrets that any allusion has been made to such matters. He has not disclaimed a measure of responsibility for the condition of affairs leading to the undertaking of the tests described, and he has no doubt but that all the engineers and contractors participating have profited somewhat by the experience.

The correction offered by Mr. Bush, that the distortion was first noticed on the 42-in. pipe, is accepted. The author feels confident, however, that the contractors did also discover a flattening of the 35-in.

Mr. Clarke.

pipe at about the same time. If not, then his notes of a conversation with the contractors' engineer and superintendent, held January 18th, 1894, and recorded on the evening of that day, and also his report of the matter to the chief engineer, dated the following day, are both in error. Whether this flattening was noticeable to the eye or not, the author has no means of knowing; but, be that as it may, the engineers lost no time in acting upon the hints received, and further investigations were promptly made independent of the examinations made by the contractors.

Mr. Bush describes one point where the 42-in. pipe was excessively flattened. Another point was 4 miles distant from the first, and near the summit of a gravelly, rocky ridge where the trench was from 7 to 11 ft. deep. This pipe was laid during the months of September and October, 1893, when the ground was perfectly dry and no water could collect in the trench, and yet, when examined, the pipe was found to be flattened from $\frac{1}{2}$ in. to $3\frac{1}{2}$ ins. The difficulty at both places described, as well as at other points examined, was that the earth at the sides, and below the top of the pipe, had not been made sufficiently compact. Unless this is done first of all, the use of tamping bars, or even horses and drag scrapers, in the top of the trench will be of little avail.

As an illustration of two methods of doing the same work, the author desires to call attention to his notes of the section of 42-in. pipe uncovered at stations 1320 + 20 to 1321 + 20. This point is also on high ground, with no chance for water to accumulate in the trench. The pipe was laid near the end of September, 1893, before any rain had fallen. When the pipe was uncovered in January, 1894, the earth around it was found to be very loose, with little under the bottom, between center and quarter. At the joint holes an open space was found 4 ft. x $1\frac{1}{2}$ ft., at the center of which the earth had not been filled to within 6 ins. of the bottom of the pipe. As stated in the notes, the measurements first taken showed a compression ranging between $1\frac{5}{8}$ ins. and $2\frac{3}{4}$ ins. Upon being uncovered the pipe expanded vertically from $\frac{1}{4}$ in. to $1\frac{5}{8}$ ins., but still it did not quite regain its original dimensions. These measurements indicate a permanent set in the pipe of between $\frac{5}{8}$ in. and 1 in., caused by the load which it had then carried continuously for eight months. The process of filling the trench the second time, carried on in compliance with the specifications, which required the earth below the top of the pipe to be tamped in 6-in. layers, only caused a further flattening of the top of $\frac{1}{8}$ in., a result most surprising to those who had been accustomed to the ordinary method of doing such work. Evidently, if the engineers and contractors had made a united effort to secure a strict compliance with the specifications, no occasion would have arisen for these notes and the tests they describe.

Mr. Clarke. Mr. Tuttle calls attention to an omission which is gladly supplied. The pipe sections were made with the straight seams alternating to right and left not more than 6 ins. from a line along the axis of the pipe. They were laid in the trench with the straight seams on top, and in the tests described they were similarly placed.